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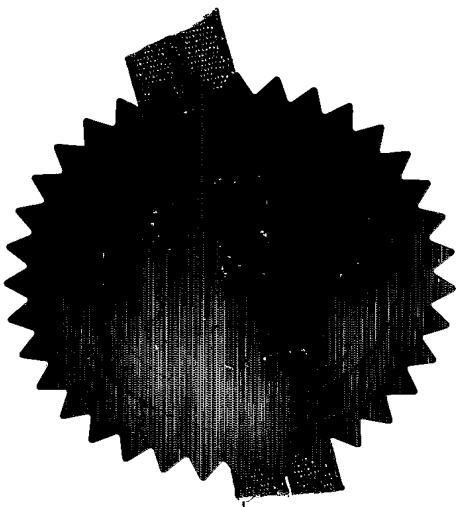
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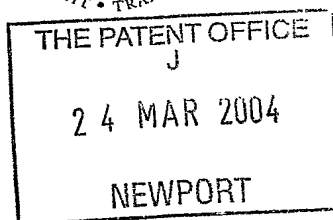


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798496019

4. Title of the invention

Improved Mode Selection and Frequency Tuning of a Laser Cavity

5. Name of your agent (if you have one)

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1 Improved Mode Selection and Frequency Tuning of a Laser
2 Cavity

3
4 The present invention relates to a method and apparatus
5 for improving the mode selection and frequency tuning of
6 a laser cavity. In particular, the invention relates to
7 the incorporation of an intracavity, anisotropic etalon
8 that provides a means for selecting and stabilising the
9 laser cavity to a single mode operating frequency.

10
11 The use of single frequency lasers relies heavily on the
12 ability to select a mode of the laser cavity and maintain
13 it for an extended period of time. This may also include
14 tracking the mode if the length of laser cavity is
15 scanned in order to change the output frequency. This
16 selection is normally carried out with a combination of
17 optical elements inserted into the cavity. These
18 elements may include birefringent filters and etalons.

19
20 In the case of widely tuneable lasers the frequency
21 selection requirements placed on these elements are
22 particularly stringent. The first requirement results
23 from the fact that the desired mode of operation is one

1 of a great number of possible modes on which the cavity
2 may operate. Secondly, the need to tune the laser
3 frequency implies that the selecting element has to be
4 tuned as well, typically by being rotated around one of
5 its axes. As a result, the non-solid mounting techniques
6 normally employed for the selecting element to be rotated
7 makes the laser frequency prone to drifting.

8

9 Two main classes of widely tuneable single frequency
10 lasers known to those skilled in the art are Dye lasers
11 and Ti:Sapphire lasers. In both cases the tuning range
12 provided by the gain medium is in excess of 50 THz (or
13 more than 100 nm). The laser cavity modes of which a
14 single one has to be selected are typically spaced by a
15 few hundred MHz. Selection is achieved by insertion
16 within the cavity of a number of optical elements, each
17 of which introduce an operating power loss that is a
18 periodic function of the laser frequency. This period is
19 referred to as the free spectral range (FSR) of the
20 element. Typically, the elements chosen to achieve
21 single frequency operation are selected to have
22 successively smaller free spectral ranges corresponding
23 to successively narrower regions of low insertion loss.
24 As a result only one laser mode is capable of oscillating
25 at a frequency corresponding to a loss minimum of all of
26 the inserted elements. The exact requirements for the
27 mode selecting elements are known to depend on the amount
28 of inhomogeneous to homogeneous broadening in the gain
29 medium as well as any spatial hole burning effects.

30

31 In a tuneable single frequency laser coarse wavelength
32 selection is typically achieved through the employment of
33 a birefringent filter within the cavity. This may

1 consist of one or more plates made of a birefringent
2 material and is rotated to select a laser bandwidth of
3 typically less than 200 GHz (0.5 nm). At this point it
4 is often sufficient just to insert a fused silica etalon
5 with a free spectral range of approximately 200 GHz into
6 the cavity to ensure single-mode operation. However, the
7 stability requirements are extremely stringent as the
8 rotation of the etalon by an angle of an order of one
9 thousandth of a degree is sufficient for the laser to
10 jump to the next mode of operation.

11

12 Two main methods have been employed by those skilled in
13 the art in order to prevent the detrimental effect of
14 mode jumping:

15

16 1) The first method comprises a passive stabilisation
17 technique that involves the addition of a second
18 etalon, with an even smaller free spectral range,
19 thereby reducing the sensitivity of the first
20 etalon. In the case of a widely tuneable laser an
21 appropriate feed-forward has to be applied to this
22 second etalon in order to track the scanning laser
23 mode. This technique has been successfully
24 implemented within the commercially available
25 Coherent 599/699/899 series of Dye lasers.

26

27 2) The second method comprises an active stabilisation
28 technique whereby a feedback is applied to the
29 rotation of a solid etalon so as to keep it locked
30 to the laser mode over long periods of time, and
31 also while the laser is being scanned. This
32 technique is employed within the commercially
33 available Coherent MBR 110 Ti:Sapphire laser 1, see

Figure 1. In particular the electronic signal required for the stabilisation is derived by modulating the angle of the solid etalon 2 at a frequency of 80-90 kHz around a reflection minimum.

Generally, it is appreciated that the fewer intracavity elements included within a laser cavity the simpler the system is to operate, as there are fewer difficulties in relation to the optical alignment of the cavity. Furthermore, the incorporation of additional elements within the laser cavity also acts to reduce the overall output power of the system as each intracavity element introduces an inherent power loss. Therefore, employing the above passive technique has particular disadvantages over that of the described active technique.

Modulating the solid etalon 2 angle so as to derive an error signal for locking the solid etalon 2 to the cavity in the above active stabilisation technique produces certain inherent detrimental effects on the operation of the laser. In the first instance, the modulated solid etalon 2 introduces a loss in the cavity at twice the modulation frequency, and hence an undesirable intensity modulation results. Secondly, the etalon 2 sets up acoustic vibrations in the cavity, which are then required to be removed through the employment of complex electronics.

It is an object of aspects of the present invention to provide a method and apparatus for improving the mode selection and frequency tuning of a laser cavity so as to overcome one or more of the limiting features associated

1 with the methods and apparatus described in the prior
2 art.

3

4 According to a first aspect of the present invention
5 there is provided apparatus for stabilising a frequency
6 output of a laser cavity comprising an intracavity
7 birefringent etalon wherein the intracavity birefringent
8 etalon is employed to derive a polarised electric field
9 component from an intracavity electric field within the
10 laser cavity, the orientation of polarisation of the
11 polarised electric field component being dependent on the
12 frequency and polarisation of the intracavity electric
13 field.

14

15 Most preferably the intracavity birefringent etalon acts
16 as a first quarter waveplate on the polarised electric
17 field component such that when the frequency of the
18 intracavity electric field corresponds to a resonant
19 frequency of the birefringent etalon the polarised
20 electric field component is linearly polarised.

21

22 Preferably the apparatus for stabilising the frequency
23 output of the laser cavity further comprises a second
24 quarter waveplate.

25

26 Preferably the apparatus for stabilising the frequency
27 output of the laser cavity further comprises an
28 elliptical polarisation analyser for analysing the state
29 of polarisation of the polarised electric field component
30 on being transmitted through the second quarter
31 waveplate.

32

1 Optionally an optical axis of the second quarter
2 waveplate is aligned with an optical axis of the
3 birefringent etalon such that on being transmitted
4 through the second quarter waveplate the polarised
5 electric field component is linearly polarised, the plane
6 of linear polarisation being dependent on the frequency
7 of the intracavity electric field relative to the
8 resonant frequency of the birefringent etalon.

9
10 Optionally the elliptical polarisation analyser comprises
11 a polarisation dependent beamsplitter and two light
12 detecting means wherein the polarisation dependent
13 beamsplitter is orientated so as to resolve the polarised
14 electric field component into two spatially separated
15 components each of which is incident on one of the light
16 detecting means.

17
18 Preferably the elliptical polarisation analyser further
19 comprises an electronic circuit wherein the electronic
20 circuit derives an error signal from electrical output
21 signals generated by the two light detecting means.

22
23 Preferably the electronic circuit further comprises a
24 feedback circuit for generating a feedback signal in
25 response to the error signal so as to control the
26 orientation of the birefringent etalon within the
27 intracavity electric field in order to minimise the
28 magnitude of the error signal.

29
30 According to a second aspect of the present invention
31 there is provided apparatus for scanning a frequency
32 output of a laser cavity comprising apparatus for
33 stabilising the frequency output of the laser cavity in

1 accordance with a first aspect of the present invention
2 and means for scanning the length of the laser cavity.

3
4 Preferably the means for scanning the length of the laser
5 cavity comprises at least one laser cavity mirror mounted
6 on a piezoelectric crystal.

7
8 According to a third aspect of the present invention
9 there is provided a method for stabilising a frequency
10 output of a laser cavity comprising the steps of:

- 11 1) Employing a birefringent etalon to sample an
12 intracavity electric field of the laser cavity so as to
13 derive a polarised electric field component whose
14 polarisation is dependent on the polarisation and
15 frequency of the intracavity electric field relative to
16 the resonant frequency of the birefringent etalon;
- 17 2) Deriving an error signal from the polarised field
18 component; and
- 19 3) Stabilising the birefringent etalon to the derived
20 error signal.

21
22 Most preferably the polarised electric field component is
23 linearly polarised when the intracavity electric field
24 corresponds to a resonant frequency of the birefringent
25 etalon.

26
27 Preferably the polarised electric field component is
28 elliptically polarised when the intracavity electric
29 field corresponds to a non-resonant frequency of the
30 birefringent etalon. In particular, the helicity of the
31 polarised electric field component is of an alternative
32 sign when the intracavity electric field frequency is

1 above or below the resonant frequency of the birefringent
2 etalon.

3

4 Preferably the derivation of the error signal comprises
5 the steps of:

6 1) Introducing a $\pi/2$ phase shift to the orthogonal
7 constituent components of the polarised electric field
8 component;

9 2) Resolving the orthogonal constituent components of the
10 polarised electric field component; and

11 3) Calculating an intensity ratio signal the orthogonal
12 constituent components of the polarised electric field
13 component.

14

15 Optionally introducing the $\pi/2$ phase shift to the
16 orthogonal constituent components of the polarised
17 electric field component results in the plane of
18 polarisation of the polarised electric field component
19 being directly dependent on the frequency of the
20 intracavity electric field relative to the resonant
21 frequency of the birefringent etalon;

22

23 Preferably the birefringent etalon is stabilised to the
24 derived error signal by controlling the orientation of
25 the birefringent etalon within the intracavity electric
26 field in order to minimise the magnitude of the error
27 signal

28

29 According to a fourth aspect of the present invention
30 there is provided a method for scanning a frequency
31 output of a laser cavity comprising:

- 1) Stabilising the frequency output of the laser cavity in accordance with a third aspect of the present invention;
- 2) Scanning an optical length of the laser cavity; and
- 3) Scanning the orientation of the birefringent etalon within the intracavity electric field in order to track the scanned optical length of the laser cavity.

Aspects and advantages of the present invention will become apparent upon reading the following detailed description and upon reference to the following drawings in which:

Figure 1 presents a schematic representation of a commercially available Coherent MBR 110 Ti:Sapphire laser that incorporates an active stabilisation technique, as known to those skilled in the art;

Figure 2 presents a schematic representation of stabilisation apparatus employed within a vertical external cavity surface emitting laser (VECSEL), in accordance an aspect of the present invention;

Figure 3 presents a schematic representation of the principle of operation of the stabilisation apparatus of Figure 2 when employed within an extra-cavity configuration;

1 Figure 4 presents both theoretical and experimental
2 curves relating to a normalised ratio signal as
3 a function of input laser frequency, for the
4 stabilisation apparatus of Figure 3 when
5 employed with an uncoated birefringent etalon;
6

7 Figure 5 presents an experimental curve of the
8 normalised ratio signal as a function of
9 birefringent etalon tuning, for the VECSEL 3 of
10 Figure 2;
11

12 Figure 6 presents theoretical curves relating to the
13 normalised ratio signal, as a function of input
14 laser frequency, for the stabilisation
15 apparatus of Figure 3 when employed with a 4%,
16 8%, 12%, 16% and 20% reflecting birefringent
17 etalon; and
18

19 Figure 7 presents theoretical curves relating to the
20 normalised ratio signal, as a function of input
21 laser frequency, for the stabilisation
22 apparatus of Figure 3 when employed with a 20%
23 reflecting birefringent etalon and where the
24 retardation of the birefringent etalon varies
25 from a value of $\lambda/8$ to $3\lambda/8$.
26

27 Referring to Figure 2 a schematic representation a
28 Vertical External Cavity Surface Emitting Laser (VECSEL)
29 3 is presented that incorporates stabilisation apparatus
30 4, in accordance with an aspect of the present invention.
31

32 The VECSEL 3 can be seen to comprise a wafer structure 5
33 mounted within a cooling apparatus 6 that is located

1 within a three mirror folded cavity arrangement. The
2 wafer structure comprises a gain medium (not explicitly
3 shown) made up of twelve 6 nm thick $\text{In}_{0.16}\text{GaAs}$ quantum
4 wells equally spaced between half-wave $\text{Al}_{0.06}\text{Ga}_{0.8}\text{As}/\text{GaAsP}$
5 structures that allow the VECSEL 3 to be optically pumped
6 at 808 nm, while generating an output in the range of 970
7 - 995 nm.

8
9 A first mirror within the cavity arrangement comprises an
10 AlAs-GaAs quarter-wave layered Bragg reflector 7 that
11 exhibits a total reflectivity greater than 99.9% centred
12 at 980 nm. A second mirror comprises a standard curved
13 cavity mirror 8 mounted on a first piezoelectric crystal
14 9, so allowing for fine adjustment of the length of the
15 cavity. An output coupler 10, mounted on a second
16 piezoelectric crystal 11, which allows for coarse
17 adjustment of the length of the cavity, is then employed
18 as the third cavity mirror. Between the curved cavity
19 mirror 8 and the output coupler 10 is located a
20 birefringent filter 12 employed to provide coarse
21 frequency selection within the cavity.

22
23 The wafer structure 5 is optically pumped by initially
24 coupling the output of a pump laser source (not shown)
25 into an optical fibre 13. Thereafter, the coupled pump
26 laser output is focussed via two input lens elements 14
27 onto the wafer structure 5.

28
29 The stabilisation apparatus 4 can be seen to comprise a
30 birefringent etalon 15 inserted with a slight angle
31 between one of its axes and an electric field 16 of the
32 VECSEL 3. The birefringent etalon 15 is coated to act as
33 a 25% reflecting etalon and so directs a reflected

1 component 17 of the incident intracavity electric field
 2 16 towards a beam steering mirror 18 that in turn
 3 reflects the field to a quarter waveplate ($\pi/4$ waveplate)
 4 19 and then onto an elliptical polarisation analyser.
 5 The first component of the polarisation analyser is a
 6 polarisation dependent beamsplitter 20 that divides the
 7 reflected electric field 17 into two components 17a and
 8 17b each of which is then incident on a photodiode 21.
 9 An electrical circuit 22 is then employed to monitor the
 10 signals detected by the photodiode (as described in
 11 detail below).

12

13 The reflection coefficient $A_r(d,R)$ for the reflected
 14 electric field 17 from the birefringent etalon 15 is
 15 given by the expression:

16

$$17 \quad A_r(\delta, R) = \sqrt{R} \frac{1 - \exp(i\delta)}{1 - R \exp(i\delta)} \quad (1)$$

18

19 where R is the intensity reflection coefficient and
 20 $\delta = 4\pi d n \cos(\theta) / \lambda$ is the phase retardation for a roundtrip
 21 of the light of wavelength λ in the birefringent etalon
 22 15 which has a thickness d and a refractive index n , and
 23 which is tilted at an angle θ to the incident beam. This
 24 reflection represents a periodic loss with a period (FSR)
 25 of $c/(2nd \cos(\theta))$.

26

27 Since the stabilisation apparatus employs a birefringent
 28 etalon 15 there are two refractive indices n_1 and n_2
 29 corresponding to the two axes of the material. Hence
 30 there are two different values d_1 and d_2 for the phase
 31 delay. In general this corresponds to different
 32 reflectivities for the two polarisations. By designing

the birefringent etalon 15 so that the difference $d_1 - d_2$ is p modulo $2p$, one polarisation of the reflected electric field 17 experiences a reflection maximum when the other has a minimum. This is equivalent to the etalon acting as a $\pi/4$ waveplate for the incident electric field 16.

The ability to stabilise and tune the VECSEL 3 is achieved by inserting the birefringent etalon 15 in the laser cavity in such a way that the direction of polarisation forms a slight angle with one of the optic axes.

To initially demonstrate this effect we first consider the stabilisation apparatus 4 when deployed within an extra-cavity configuration, see Figure 3. The orientation of the polarisation components of the input laser are represented schematically within the insert of Figure 3. Specifically, the majority of the light (intensity of this component proportional to a^2) is polarised along this axis while a component proportional to β^2 has orthogonal polarisation ($a^2 + \beta^2 = 1$). Thus, the incident electric field 16 can be written in its two components along the axes of the birefringent etalon:

$$E(t) = (\alpha E_0 \exp(i\omega t), \beta E_0 \exp(i\omega t)) \quad (2)$$

where E_0 is the amplitude and ω the frequency. The reflected electric field is then given by the expression:

$$E_r(t, \delta_1, \delta_2, R) = (\alpha E_0 A_r(\delta_1, R) \exp(i\omega t), \beta E_0 A_r(\delta_2, R) \exp(i\omega t)) \quad (3)$$

1 The operating frequency of the VECSEL 3, or the tilt
2 angle of the birefringent etalon 12, is chosen such that
3 the a^2 component is close to a reflection minimum. At
4 exact resonance the reflection of the component along
5 axis 1 vanishes and the reflected light is linearly
6 polarised 23 along axis 2. Away from exact resonance the
7 reflection is elliptically polarised with opposite
8 helicity for frequencies above 24 and below resonance 25,
9 as is expressed mathematically by Equation 3 above.

10

11 By inserting the $\lambda/4$ waveplate 19, so that its axes are
12 aligned with those of the birefringent etalon 15, the
13 transmitted light now emerges linearly polarised. For
14 the case of exact resonance 23b the polarisation is
15 orientated along axis 2 and changes clockwise 24b and
16 counter-clockwise 25b, respectively, above and below
17 resonance. It should be noted that the relative rotation
18 of the linearly polarised transmitted light by the $\lambda/4$
19 waveplate 19 would be reversed if the fast and slow axis
20 of the birefringent etalon 15 were reversed.

21

22 The incorporation of the polarising beamsplitter, which
23 is rotated 45° with respect to the axes of the
24 birefringent etalon 15, provides a means for analysing
25 the linear polarised fields 23b, 24b and 25b. For the
26 case of the on resonance polarised field 23b an equal
27 amount of light, 23c and 23d, is transmitted to both
28 photodiodes 21. However, for the cases where the
29 frequencies are above 24 and below resonance 25 the
30 amount of light transmitted to the photodiodes 21 is
31 asymmetric, the asymmetry being directly dependent on the
32 frequency shift, see components 24c 24d 25c and 25d,

1 respectively. This provides for the production of an
 2 ideal signal for stabilising and tuning the VECSEL 3, as
 3 is now described in detail.

4

5 The signal for stabilising the VECSEL 3 is a normalised
 6 ratio signal 26 given by the following expression:

7

$$8 \quad S(\delta_1, \delta_2, R) = \frac{I_2(\delta_1, \delta_2, R) - I_1(\delta_1, \delta_2, R)}{I_2(\delta_1, \delta_2, R) + I_1(\delta_1, \delta_2, R)} = \frac{2\alpha\beta \operatorname{Im}[A_r(\delta_1, R)A_r^*(\delta_2, R)]}{\alpha^2|A_r(\delta_1, R)|^2 + \beta^2|A_r(\delta_2, R)|^2} \quad (4)$$

9

10 For demonstration purposes Figure 4 presents experimental
 11 (dotted) and theoretical (solid) curves obtained for the
 12 stabilisation apparatus 4 employed within the extra-
 13 cavity configuration. In particular, the sum and
 14 difference signals, 27 and 28 respectively, as well as
 15 the ratio of the difference and sum signals 26 are
 16 presented, as a function of laser input wavelength, over
 17 three spectral ranges of the birefringent etalon 15. It
 18 should be noted that these results were obtained by
 19 employing an uncoated birefringent etalon 15.

20

21 Further confirmation of this effect can be seen from
 22 Figure 5 which presents an experimental curve of
 23 birefringent etalon 15 tuning versus the normalised ratio
 24 signal 26, for the VECSEL 3 of Figure 2, where the
 25 stabilisation apparatus 4 is now employed intracavity.
 26 In this particular set up the birefringent etalon is
 27 coated so as to reflect 25% of the intracavity electric
 28 field 16. As can be seen, as the birefringent etalon is
 29 tilted the operating frequency of the VECSEL is tuned.
 30 The normalised ratio signal 26 takes the form of a

1 sequence of continuous curves that pass through zero.
2 The discontinuities correspond to mode jumping occurring
3 in the operating frequency of the VECSEL 3.

4

5 The ratio signal 26, and in particular the positive
6 gradient sections 29, are ideal for stabilising the
7 birefringent etalon 15 to a minimum reflection point and
8 hence for stabilising the VECSEL 3. This is achieved
9 through the employment of a feedback loop (not shown) of
10 the electrical circuit. In particular, the feedback loop
11 acts to keep the birefringent etalon 15 at the zero
12 crossing points of one of the positive gradient sections
13 29. This is achieved by time integrating the ratio
14 signal and thereafter transmitting a feedback signal,
15 with the appropriate sign, so as to control the angle of
16 rotation of the birefringent etalon 15, a technique that
17 is known to those skilled in the art.

18

19 The electrical circuit 22 is also employed to provide
20 signals to the first 9 and second piezo electric crystals
21 11, thereby altering the cavity length and so altering
22 the output frequency of the VECSEL 3. The feedback
23 circuit is then employed, in conjunction with a reference
24 signal forwarded from the first piezo electric crystal 9
25 so as to allow the birefringent etalon 15 to track the
26 controlled movement of the curved cavity mirror 8 and
27 hence track the operating frequency of the VECSEL 3.
28 This provides a means for continuously scanning the
29 operating frequency of a single mode of the VECSEL 3 over
30 a range of ~40 GHz.

31

1 The robust nature and flexibility of the above
2 stabilisation apparatus 4 can be seen from the following
3 considerations of the effect on the ratio signal 26 of
4 various experimental parameters for the extra-cavity
5 configuration employed in Figure 3. In the first
6 instance, the calculated ratio signal 26 for a range of
7 birefringent etalon 15 reflectivities, namely of 4%, 8%,
8 12%, 16% and 20%, is shown in Figure 6. It is apparent
9 that the effect of increasing the reflectivity from 4%
10 (corresponding to uncoated quartz) to 20% only amounts to
11 a slight increase in the slope of the positive gradient
12 sections 29. Therefore, it will be apparent to those
13 skilled in the art that the above described method and
14 apparatus leaves the reflectivity of the birefringent
15 etalon 15 as a free parameter that can be determined by
16 the requirements of mode selection in a particular laser
17 cavity.

18

19 As the method and apparatus is employed within a tuneable
20 laser system it is also relevant to consider the effect
21 on the ratio signal 26 of a deviation from an exact
22 quarter-wave retardation of the birefringent etalon 15.
23 Generally speaking waveplates are only exact waveplates
24 for a particular wavelength. The widest bandwidth for an
25 etalon (i.e. the slowest variation of the phase
26 retardation with respect to wavelength) is obtained with
27 a true zero-order plate. Therefore, for the birefringent
28 etalon 15 that is where the difference in optical
29 thickness experienced by light polarised along the two
30 optic axes is exactly a quarter of a wavelength. This
31 generally corresponds to an extremely thin plate (tens of
32 micron), that in practice is found to be too thin for
33 practical use as an etalon. Within the VECSEL 3 a

1 thickness of the order of 0.5 mm is required for the
2 birefringent etalon 15 to perform its full function. As
3 a result a higher-order plate is required to be used
4 within the laser cavity, i.e. one where the optical
5 thickness difference was $q\lambda \pm \lambda/4$, where q is an integer.

6
7 For a quartz waveplate with an approximate thickness of
8 0.3 mm the retardation is known to vary by less than $\pm\lambda/8$
9 when the laser wavelength is varied by ± 20 nm around the
10 design wavelength. Figure 7 shows theoretical ratio
11 signal for a variation of $\pm\lambda/8$. As can be seen the ratio
12 signal 26 develops a slight asymmetry, but the zero-
13 crossing remains at the correct point while the gradient
14 at the zero-crossing remains unaffected. This clearly
15 demonstrates that the technique is robust to realistic
16 variations in retardation encountered in experimental
17 realisations of the scheme and shows that the system may
18 be readily incorporated for use within any continuous wave
19 laser system that requires to operate single frequency
20 e.g. Dye and Ti:Sapphire systems.

21
22 Aspects of the present invention exhibit a number of
23 significant advantages over the stabilisation and laser
24 tuning techniques employed in the prior art. In the
25 first instance the present system employs fewer optical
26 elements than those comprising passive stabilisation
27 systems. This makes the systems simpler to align and
28 maintain while reducing cost. Furthermore, the present
29 system does not require the employment of an etalon
30 modulation technique as used in known active
31 stabilisation systems. This is of major benefit for the
32 operation of the laser as it avoids the inherent losses
33 and acoustic vibrations introduced to the cavity by the

1 modulating etalon. A direct result of the removal of the
2 effects of acoustic vibrations is that the control
3 electronics can then be significantly simplified.

4

5 The foregoing description of the invention has been
6 presented for purposes of illustration and description
7 and is not intended to be exhaustive or to limit the
8 invention to the precise form disclosed. The described
9 embodiments were chosen and described in order to best
10 explain the principles of the invention and its practical
11 application to thereby enable others skilled in the art
12 to best utilise the invention in various embodiments and
13 with various modifications as are suited to the
14 particular use contemplated. Therefore, further
15 modifications or improvements may be incorporated without
16 departing from the scope of the invention herein
17 intended.

18



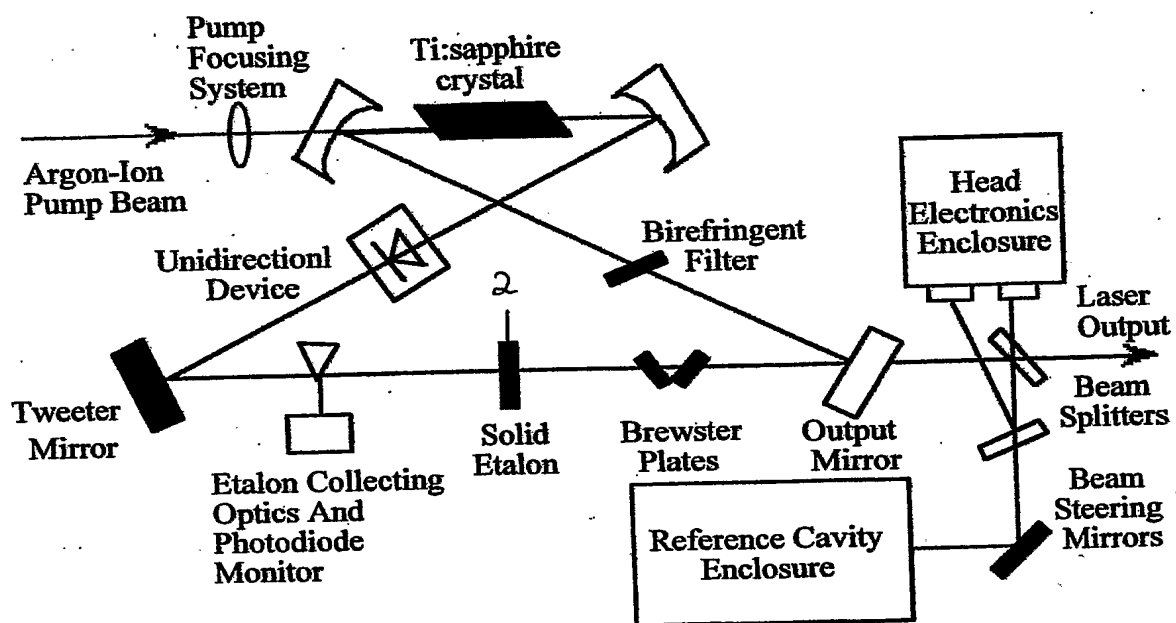


FIGURE 1



3

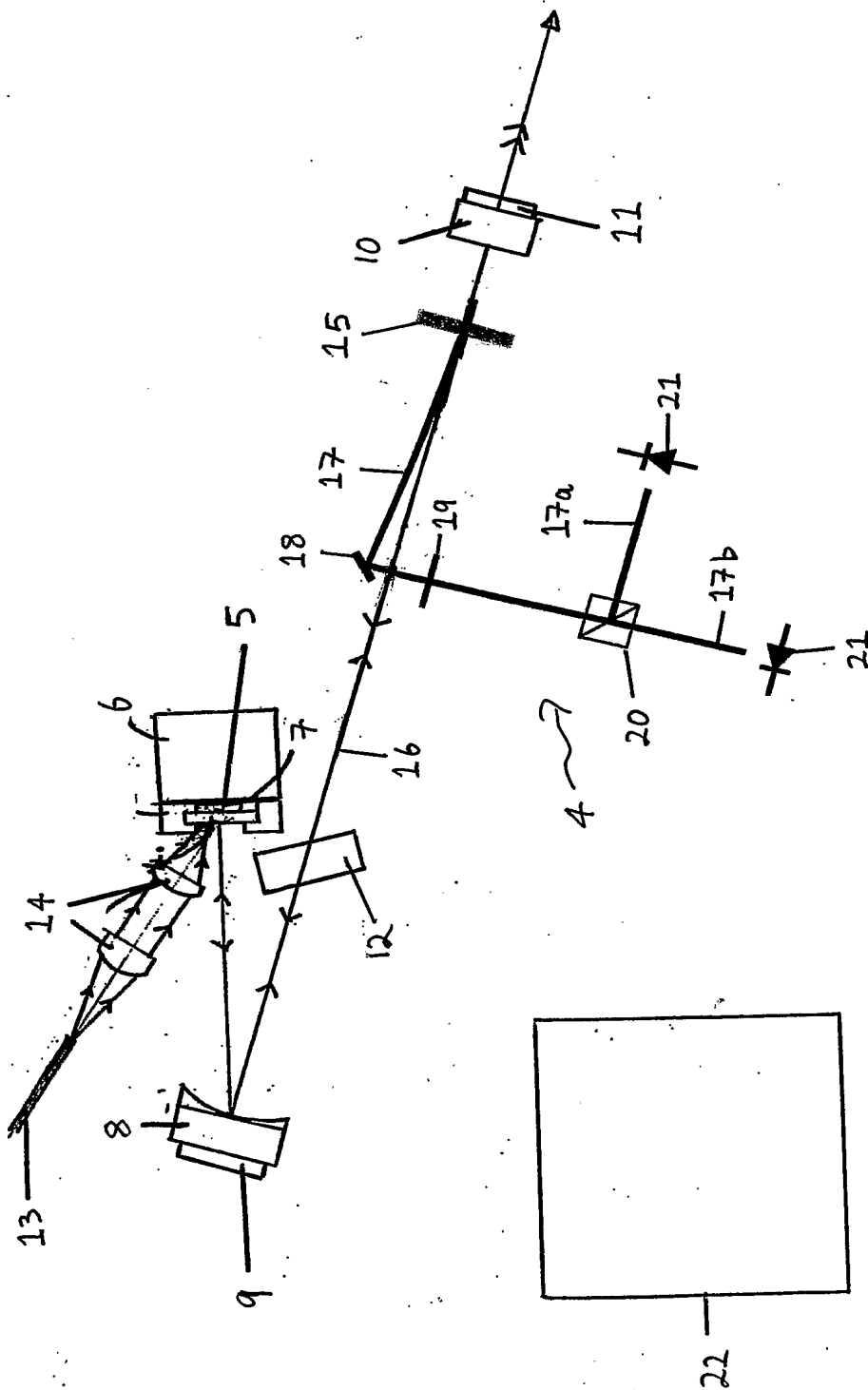


FIGURE 2



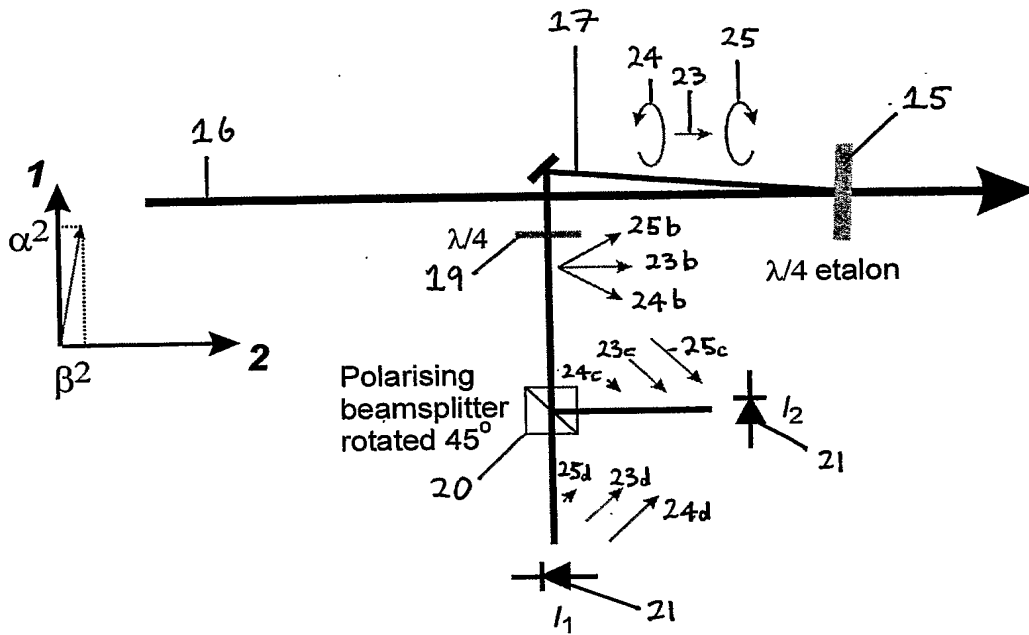


FIGURE 3

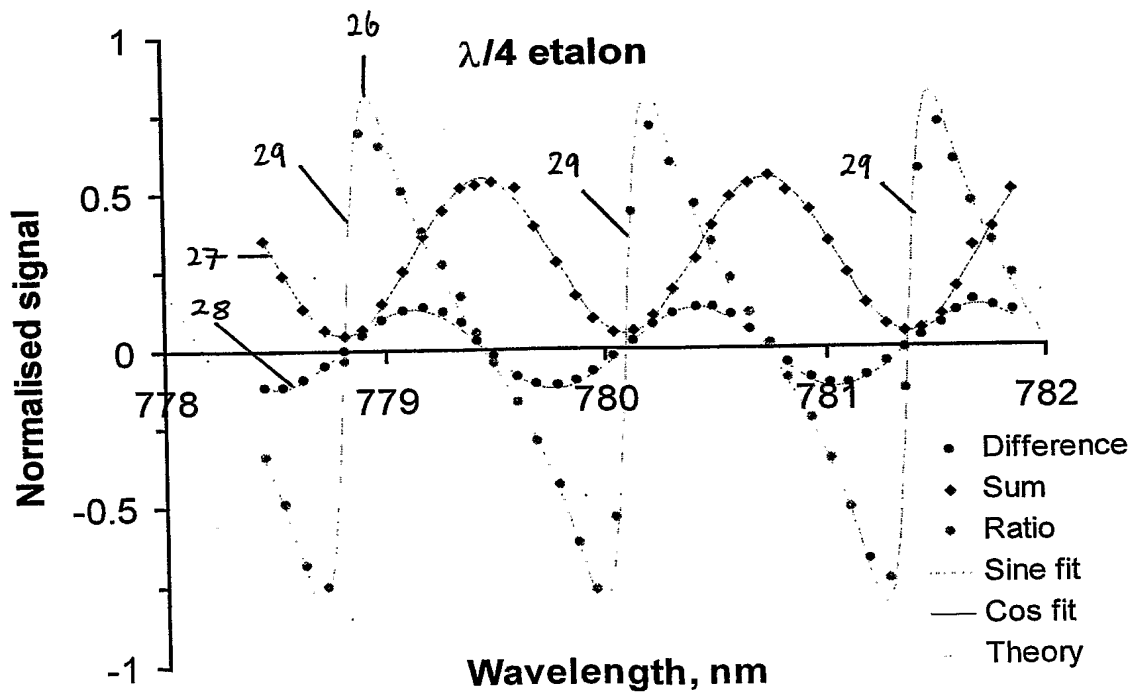


FIGURE 4



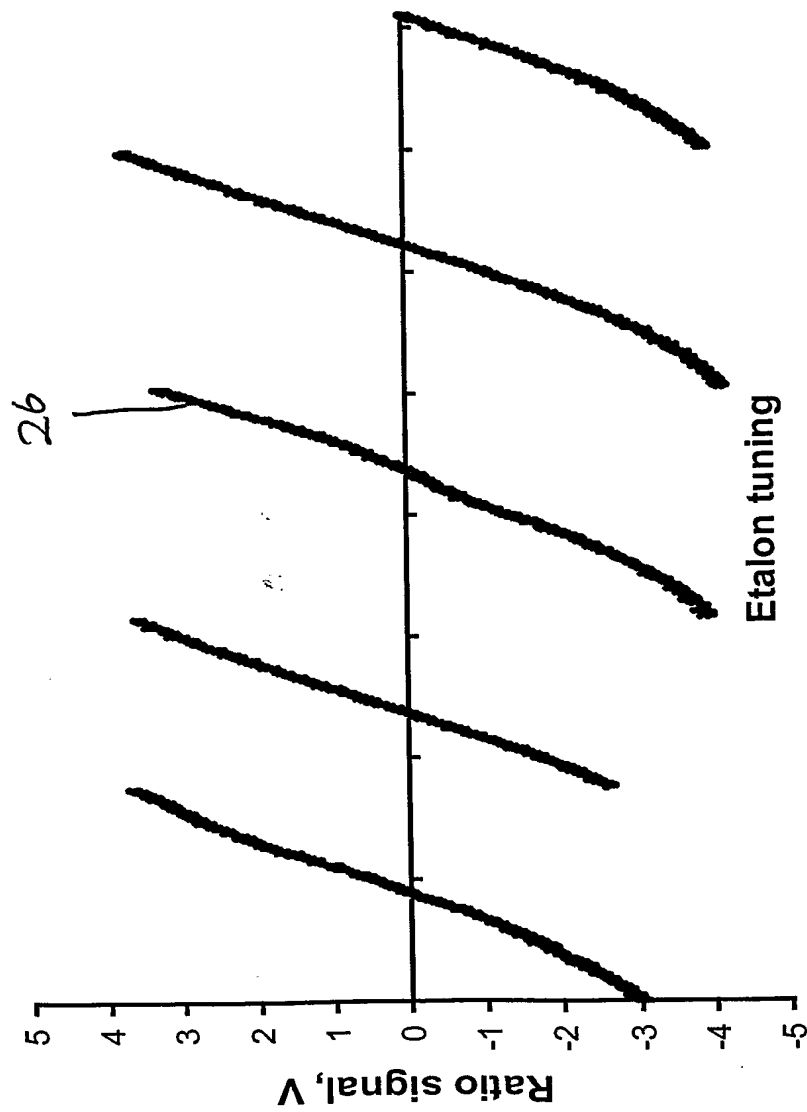


FIGURE 5



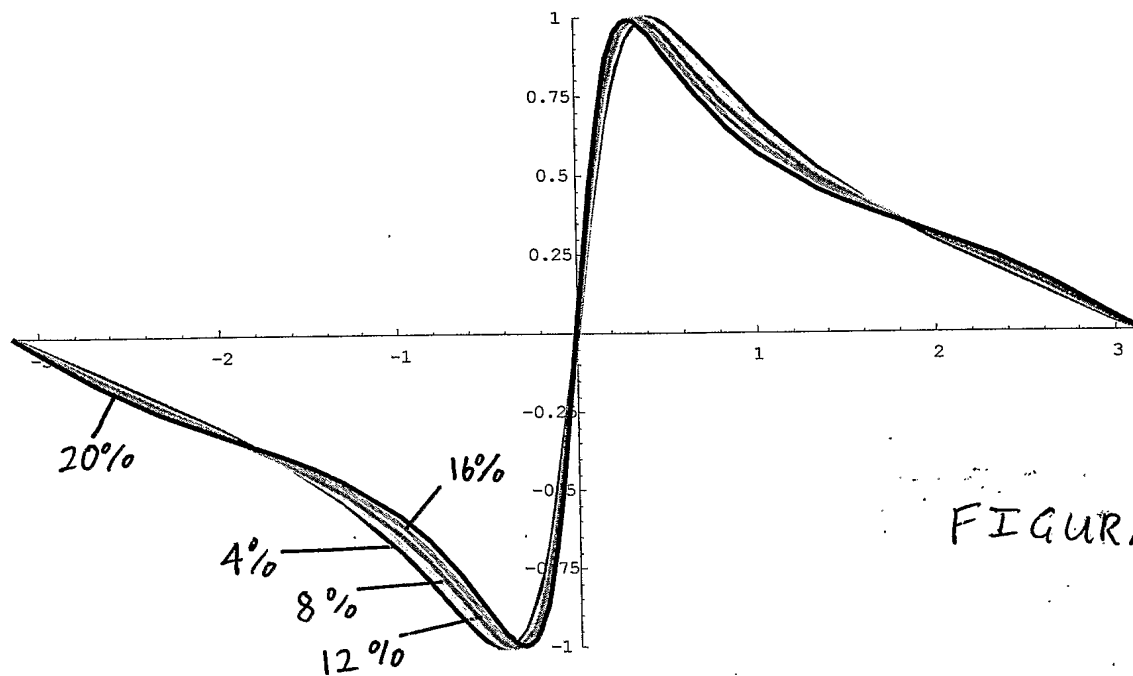


FIGURE 6

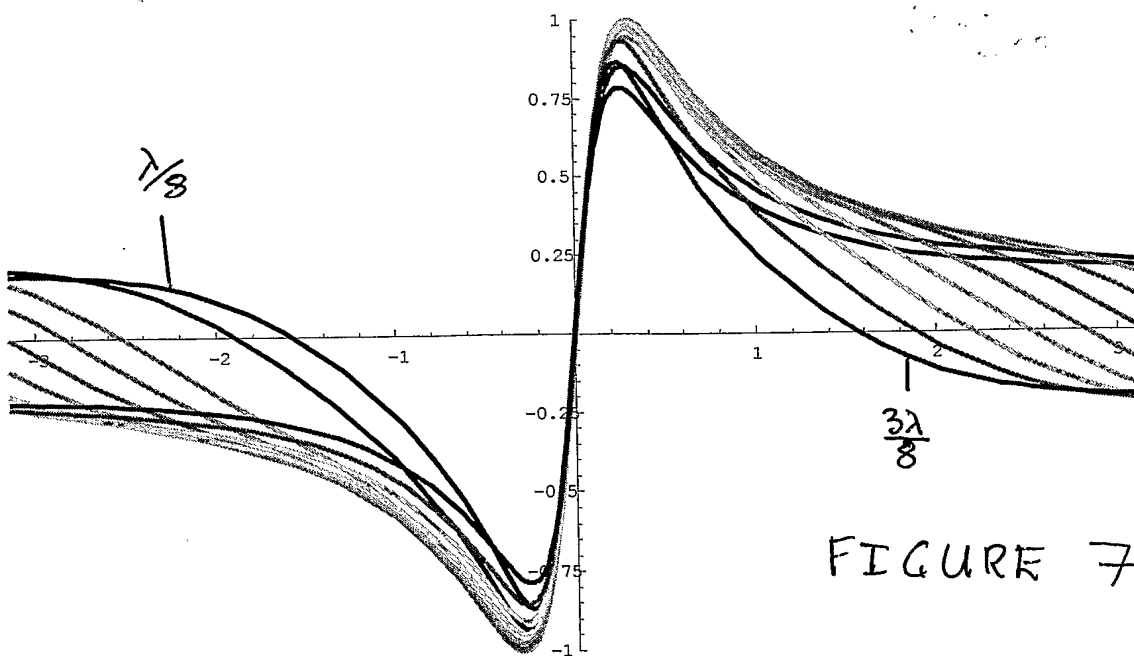


FIGURE 7

